

## *Research Summaries FY 1988-89: Upper Atmosphere Theory & Data Analysis Program*

### A. Stratospheric Chemistry and Transport

B. Dr. Michael Prather (P.I.), NASA/GISS  
Dr. Maria M. Garcia (Co-I.), Columbia U.

C. **Research Objectives** of this project were to implement chemistry in the 3-D general circulation model of the middle atmosphere developed by Dr. David Rind (GISS) under another task. The objectives were to develop an operational chemical tracer model (CTM) that used the wind fields from the GCM. The first work under this project was to use chemical tracers with simple, first-order losses such as  $N_2O$  and then to develop a successively more complex ozone chemistry. A major direction of the CTM is the examination of climate perturbations (predicted by the GCM for doubled  $CO_2$ ) and their impact on stratospheric circulation and ozone.

### D. Progress and Results

A study of the Antarctic ozone hole has been made with a 3-D chemical transport model (CTM) using a linearized photochemistry for ozone. The tracer model uses the winds and convection from the GISS general circulation model ( $8^\circ \times 10^\circ \times 23$  layers). The GCM develops an Antarctic circumpolar vortex in early winter with strong westerlies that reverse in Austral spring and the circulation compares favorably with the observed climatologies. A 4-year control run of the CTM with annually repeating winds produces ozone distributions that compare reasonably with the observed climatology. We examine different linearizations of the ozone chemistry and show that the calculated column ozone is sensitive to the chemical time constants in the lower stratosphere. In separate numerical experiments, a hypothetical Antarctic ozone "hole" is induced on September 1 and on October 1; the CTM is integrated for 1 year with a linearized model that assumes standard photochemistry, not including the heterogeneous reactions and unusual chemistry associated with formation of the ozone hole. The initial depletion, assumed to be 90% of the  $O_3$  poleward of  $70^\circ S$  between 22 and 200 mbar, amounts to about 5% of the total  $O_3$  in the Southern Hemisphere.

As the Antarctic vortex breaks down and the ozone hole is dispersed, significant depletions to column ozone, of order 10 Dobson units ( $\approx 3\%$ ) occur as far north as  $40^\circ S$  during Austral summer. One year later, only 30 % of the original depletion remains, mostly below 100 mbar and poleward of  $30^\circ S$ . The October 1 initialization is continued for a second year, the ozone hole being reinduced one year later with the same parameterization. The cumulative effects from the year before are noticeable, but add only 20 % to the depletion. A budget analysis for the southern high-latitude stratosphere (10-350 mbar  $\times$   $31-90^\circ S$ ) indicates the ozone hole is replenished equally by photochemical regeneration and by reduced transport of ozone into the troposphere, with a lesser fraction being filled in by an increased flux from the tropical stratosphere.

A model for the chemical mixing of stratospheric air over spatial scales from tens of kilometers to meters was developed (Prather and Jaffe, 1989). Photochemistry, molecular diffusion, and strain (the stretching of air parcels due to wind shear) are combined into a single one-dimensional model. The model is applied to the case in which chemically perturbed air parcels from the Antarctic stratosphere are transported to midlatitudes and strained into thin ribbon-like filaments until they are diffusively mixed with the ambient stratosphere. We find that the parcels may be treated as evolving in chemical isolation until the final mixing. When parcels reach a transverse thickness of 50-100 m in the lower stratosphere, they are rapidly dispersed by the combination of molecular diffusion and strain. The rapidity of the final mixing implies a lower limit to the vertical scales of inhomogeneities observed in the lower stratosphere.

For this sensitivity study, we consider four types of Antarctic air: a control case representing unprocessed polar air; heterogeneous processing by PSCs that has repartitioned the  $\text{Cl}_x$  and  $\text{NO}_y$  families; processing that also includes denitrification and dehydration; and all processing plus 90 % ozone depletion. Large abundances of  $\text{ClO}$ , resulting initially from heterogeneous processing of stratospheric air on PSCs, are sustained by extensive denitrification. (One exception is the case of Antarctic air with major ozone depletion in which  $\text{ClO}$  is converted rapidly to  $\text{HCl}$  upon release of small amounts of  $\text{NO}_x$  as a result of the extremely non-linear  $\text{Cl}_x$ - $\text{NO}_y$  chemical system.)  $\text{ClO}$  concentrations in the midlatitude stratosphere should be enhanced by as much as a factor of 5 due to the mixing of air processed around the Antarctic vortex and will remain elevated for most of the following season.

Chemical propagation of the Antarctic ozone hole occurs in two phases: rapid loss of ozone in the heterogeneously processed parcels as they evolve in isolation; and more slowly, a relative recovery of ozone over the following months. Another important effect is the transport of denitrified Antarctic air reducing  $\text{NO}_x$  and hence the total catalytic destruction of ozone throughout the southern midlatitudes. In Antarctic air that has already been depleted of ozone within the vortex, little additional loss occurs during transport, and the propagation of chemically perturbed air acts partially to offset the deficit at midlatitudes caused by dynamical dilution of the ozone hole. In air which has not experienced substantial ozone loss, chemical propagation can generate a net ozone deficit of order 2-3 % at midlatitudes, which may be part of the recently detected trend at northern midlatitudes in late winter.

#### **E. Publications:**

Michael J. Prather and José M. Rodriguez. Antarctic Ozone: Meteoric Control of  $\text{HNO}_3$ , *Geophys. Res. Lett.*, 15, 1-4, (1988).

Michael J. Prather. European Sources of Halocarbons and Nitrous Oxide: Update 1986, *J. Atmos. Chem.*, 6, 375-406, (1988).

Michael J. Prather, ed. An Assessment Model for Atmospheric Composition, NASA Conference Publication, CP-3203, 64 pp, (1989).

Michael Prather, María M. García, Robert Suozzo, David Rind. Global Impact of the Antarctic Ozone Hole: Dynamical Dilution with a 3-D Chemical Transport Model, *J. Geophys. Res.*, 94, xxxx-xxxx, (1989).

Michael J. Prather and Andrew H. Jaffe. Global Impact of the Antarctic Ozone Hole: Chemical Propagation, *J. Geophys. Res.*, 94, xxxx-xxxx, (1989).

[3-D model results in:] Jackman, C.H., R.K. Seals Jr. and M.J. Prather, eds. 2-D Intercomparison of Stratospheric Models, NASA Conference Publication, CP-3042, 608 pp, (1989).

# **General Circulation Modeling of Stratospheric Dynamics and Transport**

Byron A. Boville and Jeffrey T. Kiehl

National Center for Atmospheric Research  
P.O. Box 3000  
Boulder CO 80307

## **Research Objectives**

The purpose of the research funded under this proposal is to develop and use three dimensional models of stratospheric dynamics and transport together with simplified chemistry to further our understanding of the stratosphere. The dynamical model will be tested at several resolutions with simplified forcing in order to determine the resolution required for transport experiments. The generation of equatorial waves in the model will be studied for varying vertical resolution and tropospheric physical parameterizations in order to determine the feasibility of simulating the quasi-biennial oscillation (QBO). The research on transport will begin with the advection of small number of species (two or three) with parameterized chemistry.

## **Summary of Progress**

During the five months that this proposal has been funded, several of the proposed projects have been initiated. The implementation of a diurnal cycle has been completed and a study of tides in the troposphere and stratosphere is in progress. The radiation parameterization has been further refined to include the effects of Voigt line shapes and the (apparently significant) effects on the stratospheric circulation are being studied.

Short (150 day) simulations at three vertical resolutions (with level spacings of about 3km, 1.5km and 700m) have been performed to examine the effect of vertical resolution on the generation, propagation and absorption of the short vertical wave length, equatorially trapped mixed Rossby gravity waves believed to be important in forcing the QBO. Early analysis indicates that a doubling of the vertical resolution over that typically used may be sufficient to represent these waves adequately, which may make an attempt to simulate the QBO feasible in the near future.